NBS TECHNICAL NOTE 845

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Cost Analysis for Computer Communications

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Cost Analysis for Computer Communications

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FOREWORD

This report is one of a series of publications produced by the Institute for Computer Sciences and Technology, National Bureau of Standards, under Grant AG-350 from the National Science Foundation.

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1. Primary Issues in User Needs
   D. W. Fife
   Chapter 10 in Networks for Research and Education: Sharing of Computer and Information Resources Nationwide
   MIT Press, Cambridge, Mass.
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2. Some Technical Considerations for Improved Service to Computer Network Users
   T.N. Pyke, Jr.
   COMPCON, 1973
   Seventh Annual IEEE Computer Society International Conference

3. Computer Networking Technology - A State of the Art Review
   T.N. Pyke, Jr. and R.P. Blanc
   COMPUTER Magazine
   Computer Society of the IEEE
   August, 1973

4. Review of Network Management Problems and Issues
   A.J. Neumann
   NBS Technical Note 795, October 1973

5. Annotated Bibliography of the Literature on Resource Sharing Computer Networks
   R.P. Blanc, I.W. Cotton, T.N. Pyke, Jr., and S.W. Watkins
   September, 1973
   NBS Special Publication 384

6. Network Management Survey
I. W. Cotton
NBS Technical Note 805, January 1974

7. User Procedures Standardization for Network Access
A. J. Neumann
NBS Technical Note 799, October 1973

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I. W. Cotton
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R. P. Blanc
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A. J. Neumann
NBS Technical Note 802, December 1973

12. Quality Service Assurance Experiments
R. Stillman
NBS Technical Note 800, December 1973

13. A Guide to Networking Terminology
A. J. Neumann
NBS Technical Note 803, March 1974

14. Research Considerations in Computer Networking
D. W. Fife
NBS Technical Note 801, June 1974

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COST ANALYSIS FOR COMPUTER COMMUNICATIONS

Robert P. Blanc

This report summarizes a communication cost study relevant to the needs of the NSF Networking for Science Program. The primary purpose of this report is to provide an approximation to the communications costs of connecting a specified number of host computers in selected locations with a specified number of interactive user terminals. Cost factors from existing, proposed, and modeled value-added networks are applied to hypothetical traffic demands to arrive at cost estimates.

Key words: Computer networking; cost study; interactive terminals; value-added networks.

1. INTRODUCTION

This report summarizes a communication cost study relevant to the NSF Networking for Science Program [1]. The primary purpose of this report is to provide an approximation to the communication costs of connecting a specified number of host computers in selected locations with a specified number of interactive user terminals. The actual numbers and locations are hypothetical, but the methodology presented can be applied to refine this, and similar studies, as actual numbers and locations become known.

Two actual and one modeled communication network will be considered. The two actual communication networks are "value-added networks" (VAN). A VAN utilizes the existing common carrier networks for transmission while providing the added data service features with separate equipment [2]. These added service features include: store-and-forward message switching, which provides for statistical multiplexing of common carrier circuits among multiple terminals and host computers; terminal interfacing which can provide for multiplexing of terminals, speed recognition, and code conversion; host interfacing to the network which thus completes the interconnection of the hosts, the terminals, and possibly other host computers. The third network considered is a hypothetical one configured by a computer program using traffic demands, size, and locations as inputs, and cost and topology as output. Once configured, this network exhibits the same properties in terms of value-added data services as the VAN's and will be so considered.

The functional capabilities and the inherent limitations of the communications networks for application in the Networking for Science Program have been discussed in detail in the technology review [3]. This report, therefore, will concentrate on costs. Sample network sizes and host and terminal locations are chosen, and communication cost factors reflective of the three networks are identified. Then those cost factors are applied against the sample configurations, using hypothetical traffic demands, to arrive at cost approximations for the application of the selected VAN's. The traffic demands are reflective of the line utilization of interactive terminals, for which data is available [4,5].

Before presenting the analysis and derived costs, the following will be discussed: the hypothetical configurations relative to numbers and locations of hosts and terminals selected for this study; a rationale for the communication networks used and the identification of their associated cost factors; the derivation of traffic demands generated by the selected terminals.

NOTE: The identification of certain commercial networks in this report is done in order to adequately identify the network technologies and cost factors discussed herein, and in no sense does it imply recommendation, endorsement, or criticism by the National Bureau of Standards.

2. CONFIGURATIONS TO BE ANALYZED

For this study the important elements of configuration are the numbers of host computers and user terminals that must be interconnected. Other typical elements such as network topology, components, and circuits are predetermined in the VAN's. The price structures of two of the VAN's used are distance independent, i.e., charges are based on the amount of data transmitted, not the distances of transmission. Actual locations will not be important for these. The hypothetical network does, however, depend on actual locations. Therefore, when there are multiple hosts, they are distributed in the largest cities throughout the country to make the configuration somewhat typical of a national network. Terminals are assumed to be located in large cities other than those in which hosts exist.

Six sample configurations, differing in size, have been selected for cost analysis. The sample configurations are as follows:

A. 1 server / 10 terminals
B. 1 server / 100 terminals
C. 10 servers / 100 terminals
D. 10 servers / 1000 terminals
E. 25 servers / 250 terminals
F. 25 servers / 2500 terminals

Servers are those locations that have a host computer providing service through the communication network. Terminals are typical 110 baud full-duplex or half-duplex interactive terminals. It is assumed that all terminals are remote from the host computers, that is, local traffic for a host computer will not enter into the analysis.

A widespread national distribution is assumed for both servers and terminals. Further, the configurations allow any terminal to connect to any host. Computer-to-computer communication is omitted from the traffic demand and cost considerations.

The sample configurations and associated costs, used in combination with the incremental costs which will also be derived, should be useful for indicating approximate costs for other similar configurations.

3. COMMUNICATION NETWORKS USED

The cost study reflects the technologies of two existing networks, TYMNET and ARPANET, and of one hypothetical network. In the case of TYMNET, the cost factor data is derived from the TYMNET commercial rates. However, lacking cost data from the ARPANET, the illustrative rates of the Packet Communications Inc. (PCI) proposal are used [6]. The third set of cost factors is derived using the Teleprocessing Systems model developed under contract by General Electric Corporation for the Office of Telecommunications Policy [7]. The TYMNET and PCI costs will be used to give an approximation to the costs of using a commercial value-added network for computer communication service and the Teleprocessing Systems Model will be used to approximate the equipment and circuit costs of constructing a value-added network. All three communication networks have widely varying capabilities. The three selections are briefly discussed below.

TYMNET is a logical selection since it is already in the business of offering a commercial value-added communication service with user supplied hosts. Among its present customers are the National Library of Medicine, Massachusetts General Hospital, Ohio State University, University of Illinois at Chicago, University of Colorado Medical Center, National Medical Audio and Visual Center, and many others.

The ARPANET, because of its extensive capabilities, is also used. Lacking an economic study of the ARPANET, there are no good, comprehensive figures for its actual cost of usage. PCI, however, has made a formal filing to operate a commercial packet switching network based on ARPANET technology. In that proposal are specified some illustrative rates which are comprehensive in the coverage of the important facets of network communication including host and terminal interfacing. Although the proposal is not identical to ARPANET technology, it is similar. For this reason, although the rates are estimates, it is believed by this author that they represent reasonable approximations for a commercial offering utilizing ARPANET technology. It is important to note that PCI illustrative rates are used, but that it is the present state of the ARPANET and its present limitations that are considered to determine traffic handling capabilities. This will be most apparent in the succeeding sections where the costs of servicing echoplex terminals are considered.

The Teleprocessing Systems Model was also used to generate communication networks used in the analysis. The communication networks generated are in many ways similar in structure to the GE Information Services communication network, except that the technology

used in the GE central communication complex is applied to a nationally distributed configuration (see technology review [3]). The networks generated can be considered to be composed of off-the-shelf components (concentrators, multiplexers, and common carrier provided circuits) although the concentrators have some relatively simple message switching capabilities which might require development. The cost figures which will be used include no overhead for operation costs, no software development costs, and no profit margin. They are essentially direct operating costs for an "off-the-shelf" system. This is an important distinction when comparing the costs of using the modeled network with those of using the commercial packaged offerings.

4. COST FACTORS

The purpose of this section is to show the cost factors which were used in the cost analysis for the six (6) sample configurations. These cost factors were obtained from: TYMNET commercial rates; the illustrative rates of the PCI proposal; and component costs and common carrier tariffs from the data bases of the Teleprocessing Systems Model.

(1) TYMNET Commercial Rates

The factors below express a breakdown of TYMNET communication charges. The accumulative connect time includes that of all terminals together connected to the host or hosts of a customer for a period of one month. The TYMCOM is the minicomputer which acts as a host computer interface to the TYMNET and requires usually minor modifications for different host systems. The cost of those modifications is reflected in "other charges." Note that the cost per unit of connect time decreases as the total connect time in a month increases.

DESCRIPTION	CHARGE
Each log-on	$ .50
Accumulative connect time per month for all terminals:	
0 to 500 hours	3.00/hour
next 1500 hours	2.50/hour
next 3000 hours	2.00/hour
next 5000 hours	1.50/hour
each hour over 10,000	1.00
Transmission of characters	.125/1000 chars.
TYMCOM-III rental (up to 30 ports)	2150.00/month
OTHER CHARGES	
One-time engineering installation charge	1000.00/TYMCOM
Programming assistance for changes to TYMCOM-III	300.00/day plus travel and living expenses

(2) PCI Illustrative Rates

PCI illustrative rates are based on the amount of traffic in terms of packets generated to and from a host computer on a monthly basis, the cost of the host computer interface, and the terminal connect time. In the next section on "traffic calculations" a derived transition from terminal input and output to packets is shown, but in general a packet is a unit composed of from zero to 1000 data bits. The accumulative number of packets is reflected of the amount of traffic to and from a customer's host computer. Traffic accumulations across multiple hosts of a single customer are not additive in the rate per packet calculation. The host interface costs, in addition to reflecting connectivity and maximum instantaneous throughput, also include a hardware channel (CIU) and host resident control program (NCP) development and usage. It should be noted that in the following illustrative rates, the rate per 1000 packets is traffic volume dependent. It should not be assumed that the rates of PCI or any other VAN will exhibit this dependency when actually operational.

TRAFFIC

M-F, 8:00 a.m. - 8:00 p.m.	Rate/1000 packets
first 1.5 million	$4.00
next 1.5 million	3.50
next 3.0 million	3.00
next 3.0 million	2.50
additional	2.00

All other times	Rate/1000 packets
first 1.5 million	$2.00
next 1.5 million	1.75
next 3.0	1.50
next 3.0	1.25
additional	1.00

HOST INTERFACE

Description	Peak Data Rate	Installation	Monthly
single connect	9.6 Kbps	$2500	$2000
single connect	50.0 Kbps	3000	2500
double connect	9.6 Kbps	3000	2500
double connect	50.0 Kbps	3500	3000
computer interface unit (CIU)		2000	500
network control program (NCP)		3500	750

CONNECT TIME

Asynchronous, switched (duplex)	Rate/minute/terminal
300 baud or less (full or half)	$0.03
300 - 1800 (half)	0.04
300 - 1800 (full)	0.05
300 - 1800 (receive), 150 or less (transmit)	0.04

Synchronous, switched	Rate
2000 or 2400 (half)	$0.08
2000 or 2400 (full)	0.09
4800 (half)	0.10
4800 (full)	0.11

FULL-TIME

Asynchronous, leased	Installation	Monthly
300 or less	$100	$150
300 - 2400 (half)	200	200
300 - 2400 (full)	200	200
300 - 2400 (receive), 300 or less (transmit)	200	200

Synchronous, leased	Installation	Monthly
2000 or 2400 (half)	$300	$350
2000 or 2400 (full)	300	350
4800 (half)	300	450
4800 (full)	300	450

(3) Teleprocessing Systems Model

The Teleprocessing Systems Model structures a tree or ring net according to demand requirements, using presently available concentrators, multiplexers, simple store-and-forward switches and common carrier offerings. Leased lines compatible with demand requirements are used between computers, concentrators, and multiplexers, and dial-up facilities are used between user terminals and the interface to the configured network.

5. TRAFFIC CALCULATIONS

For the purpose of this analysis, it is assumed that network traffic will be generated by interactive terminals operating at a data rate of 110 baud. Interactive terminal input and output is assumed because it is believed to represent, at least in the early stages, the primary mode of user interaction with the network. The data rate selection of 110 baud is due to the pragmatic consideration of being the data rate for which the most line utilization data is available. The estimated line utilization generated by interactive terminal users is based upon the Jackson and Stubbs "data stream" model and derived data for scientific users [4] and from preliminary data generated by the NBS-ICST Network Measurement Machine [5].

The line utilization is expressed in terms of the average characters per second transmitted by the user and the average characters per second transmitted by the system, and also the combined average transmitted by both. This line utilization will be some fraction of the maximum possible utilization. For example, the maximum possible for a 110 baud terminal is 10 characters per second. Since terminals may not be constantly connected to a system port during a period, what is actually being calculated is the line utilization during a terminal port second or port hour. However, since statistics are not available covering actual terminal-port connect time for the wide variety of users and usages in the Networking for Science Program, an excess demand situation will be assumed. Therefore, a terminal will be connected and in use during the entire period of interest. This will allow us to equate line utilization per terminal to line utilization per port hour. Total network traffic will be the amount of traffic generated by one terminal (calculated from line utilization) multiplied by the number of terminals in the network.

Line utilization will be expressed in units which are useful for cost analysis in relation to the respective communications cost factors of the VAN's. Bits per second input and output are useful for specifying a task description for the Teleprocessing Systems Model. Characters per second and total characters generated are most relevant to the TYMNET commercial rates. For the PCI illustrative rates, it is the number of packets generated that is the important variable. The latter, since it can only be speculated how PCI would map interactive terminal traffic into packets, is derived by assuming that buffer sizes in the terminal interface will be similar to those of the NBS TIP and that interactive terminals will be handled similar to the manner in

which they are presently handled on the ARPANET. The actual transition between interactive terminal traffic and ARPANET packets is described in the literature [3, 8].

It is important to point out that the following calculations for packets per month in the full duplex case are based strictly on the current ARPANET mode of operation. At this time efforts are directed toward a new Telnet protocol, which when used in the optional "Remote Controlled Terminal Echoing (RCTE)" mode, is expected to have a substantial effect on the numbers of packets which will be required in full-duplex operation. PCI's plan has been to make available a terminal protocol similar in effect to that expected from the new protocol. Lacking statistics as to the actual blocking of data into packets under such a protocol, the current ARPANET mode is used in the analysis. This does not imply that PCI, other potential commercial offerings, or a revised ARPANET protocol will operate in that same mode.

For all cases it is necessary to know the number of connects made by the terminal, the duration of connection, and the actual times of the day (prime time or otherwise). Therefore it is assumed that terminals are used continuously during prime time (9:00 a.m. - 5:00 p.m., Monday - Friday) for 16 one-half hour sessions. Enough data is given in the report to permit a similar analysis under different assumptions.

The different transformations for the same flow of traffic is shown below:

LINE UTILIZATION PER TERMINAL

(1) Characters per month = 2300K:

$$3.6\,\frac{\text{char}}{\text{sec}}\,[1] \times 3600\,\frac{\text{sec}}{\text{hour}} \times 8\,\frac{\text{hour}}{\text{day}} \times 22\,\frac{\text{day}}{\text{month}} = 2300\text{K}\,\frac{\text{char}}{\text{month}}$$

(2) Connects per month = 352:

$$8\,\frac{\text{hour}}{\text{day}} \times 22\,\frac{\text{day}}{\text{month}} \times 2\,\frac{\text{connects}}{\text{hour}} = 352\,\frac{\text{connects}}{\text{month}}$$

(3) Packets per month - half-duplex = 88.7K:

2300K (char) = 180K (input) + 2120K (output)[2]

$$\frac{180\text{K}}{10}\ (\text{input buffer}) + \frac{2120\text{K}}{30}\ (\text{output buffer})\,[3] =$$

$$18\text{K (input)} + 70.7\text{K (output)} = 88.7\text{K}\,\frac{\text{packets}}{\text{month}}$$

(4) Packets per month - full-duplex = 430.7K:

180K (input) + 180K (echo)[4] + 2120K (output) = 2480K (char)

$$\frac{180\text{K}}{1}\ (\text{input buffer}) + \frac{180\text{K}}{1}\ (\text{echo buffer})\,[5] + \frac{2120\text{K}}{30}\ (\text{output buffer}) =$$

$$430.7\text{K}\,\frac{\text{packets}}{\text{month}}$$

(5) Input/output bits per hour = 11.9K input, 130.7K output:

$$3.6 \frac{\text{char}}{\text{sec}} = 39.6 \frac{\text{bits}}{\text{sec}}\text{[6]} = 142.6\text{K} \frac{\text{bits}}{\text{hour}}$$

$$\text{input} = 11.9\text{K} \frac{\text{bits}}{\text{hour}} \qquad \text{output} = 130.7\text{K} \frac{\text{bits}}{\text{hour}}\text{[7]}$$

NOTES:

1. Derived from data used with the "data stream" model [4] for scientific users on a moderately loaded system.

2. Input/output ratio is derived from data of the "data stream" model.

3. Buffer sizes are those of the NBS TIP. It is assumed that message sizes are such that the buffers are fully utilized.

4. Echoing here is, in quantity, one-to-one with input. It is assumed that the action of echoing will not significantly alter input and output demands.

5. The system will try to transmit characters immediately rather than batching characters which would result in choppy echoing (see the technology review [3] for a complete discussion of this concept).

6. This is the number of bits seen at the terminal interface.

7. These ratios are derived from the "data stream" model.

6. COMMUNICATIONS COSTS

The previous sections describe the configurations used, the cost factors for the three communication networks, and the traffic demands of interactive terminals. This section shows the derived communications costs applying the cost factors of each of the three communication networks to the selected sample configurations using the hypothetical terminal traffic demands. First, two sample calculations are shown and then the costs from all calculations are summarized in tabular and graphical format. For comparative purposes, some typical common carrier offerings are summarized. For the details of each cost calculation, see Appendix A, and for a listing of typical common carrier rates, see Appendix B.

In the following calculations, the costs of the terminals themselves, the local loops and modems, and the host computers are assumed constant across networks and are factored out of the analysis. The cost of running the network control program, that software in the host computer that enables it to communicate with the network, is relevant, but there are no useful data to describe this cost in terms of main memory and CPU utilization. It is, therefore, also omitted. These sample calculations are based on the configuration requiring 10 host computers or server systems and 1000 interactive terminals. The calculations are performed for TYMNET rates and PCI illustrative rates. The reader should refer back to sections 4 and 5 for the cost factors and traffic assumptions.

In the case of TYMNET, the cost for interconnecting 10 servers with 1000 user terminals consists of: an installation charge composed of a one-time engineering charge and a programming assistance charge; and a monthly charge based on the total number of connects, the number of characters transmitted and received, and the accumulative connect time for all terminals. The engineering installation charge can be calculated as

$1000 x 34 = $34,000 or $3400 per host

which is the cost of 34 TYMCON-III's, giving a capacity of 1020 ports (30 ports per TYMCON-III). Assume an average of $4000 per TYMCON-III for programming assistance for unique host systems. If, in the worst case, we have 10 unique host systems (hardware and/or software), then the charge can be calculated as

$4000 x 10 = $40,000 or $4000 per host

or a total installation charge of $7400 per host. The rental charge for the TYMCOM 111's is $73,100/month ($2150 x 34) or $73.10 per terminal and the log-on charge is

$.50 x 352 (1 log-on per connect) = $176 per terminal.

The charge for transmitting characters can be calculated as

$.125 x 2300K = $287.50 per terminal.

The accumulative connect time per month for all 1000 terminals is 176,000 hours which, using the sliding scale on page 6 gives a total cost of $184,750 or $184.75 per terminal. Therefore, the monthly charge adds to $721.35 per terminal. The minimum possible communication charge per terminal occurs when the accumulative connect time for all terminals is great enough such that the effective rate per hour approaches the minimum value of $1/hour. In that case the connect time charge per terminal would approach $176/month. The cost is further decreased by allowing the number of ports (terminals simultaneously connected) to be an even multiple of 30 (30 ports per TYMCOM-111), giving a TYMCOM-111 rental charge of $71.67 per terminal. The minimum monthly cost is therefore given as

$71.67 + $176 + $287.50 + $176 = $711.17 per terminal.

A similar calculation can be performed using the PCI illustrative rates. The configuration of 10 servers and 1000 terminals is again used, and for the purposes of this calculation, the terminals operate in half-duplex mode. The charges consist of: an installation charge for the host interface; and monthly rental charges for the host interface, terminal connect time, and terminal traffic. The reader should note that the following calculations are based only on the illustrative rates of PCI and that these rates are subject to change before a service is actually offered. The installation charge for each host interface, assuming that single connectivity between the host and the network and a peak data rate of 9600 baud are sufficient, is calculated as

$2500 + 2000 + 3500 = $8000 per host.

This includes the computer interface unit and the network control program. The monthly charge for the same is

$2000 + 500 + 750 = $3250 per host.

With 10 hosts and 1000 terminals the host interface cost per terminal

averages to \$32.50. The monthly connect time charge is

$$\frac{\$.03}{\text{min}} \times \frac{60 \text{ min}}{\text{hour}} \times 176 \text{ hours} = \$316.80 \text{ per terminal.}$$

The monthly charge for terminal traffic is accumulative on a host computer basis, but is non-accumulative across hosts. Therefore using the traffic estimates from section 5 we have

$$88.7\text{K} \times 100 = 8870\text{K packets per host}$$

which is the average number of packets per terminal multiplied by the average number of terminals per host. Applying the sliding scale on page 7 leads to a monthly traffic charge of \$27,425 per 100 terminals or \$274.25 per terminal. The total monthly charge is therefore

$$\$32.50 + \$316.80 + \$274.25 = \$623.55 \text{ per terminal.}$$

The minimum cost per terminal is calculated by allowing the amount of traffic to be great enough such that the rate per 1000 packets approaches the minimum on the sliding scale. At the limit the monthly cost is

$$\$32.50 + \$316.80 + \$177.40 = \$526.70 \text{ per terminal.}$$

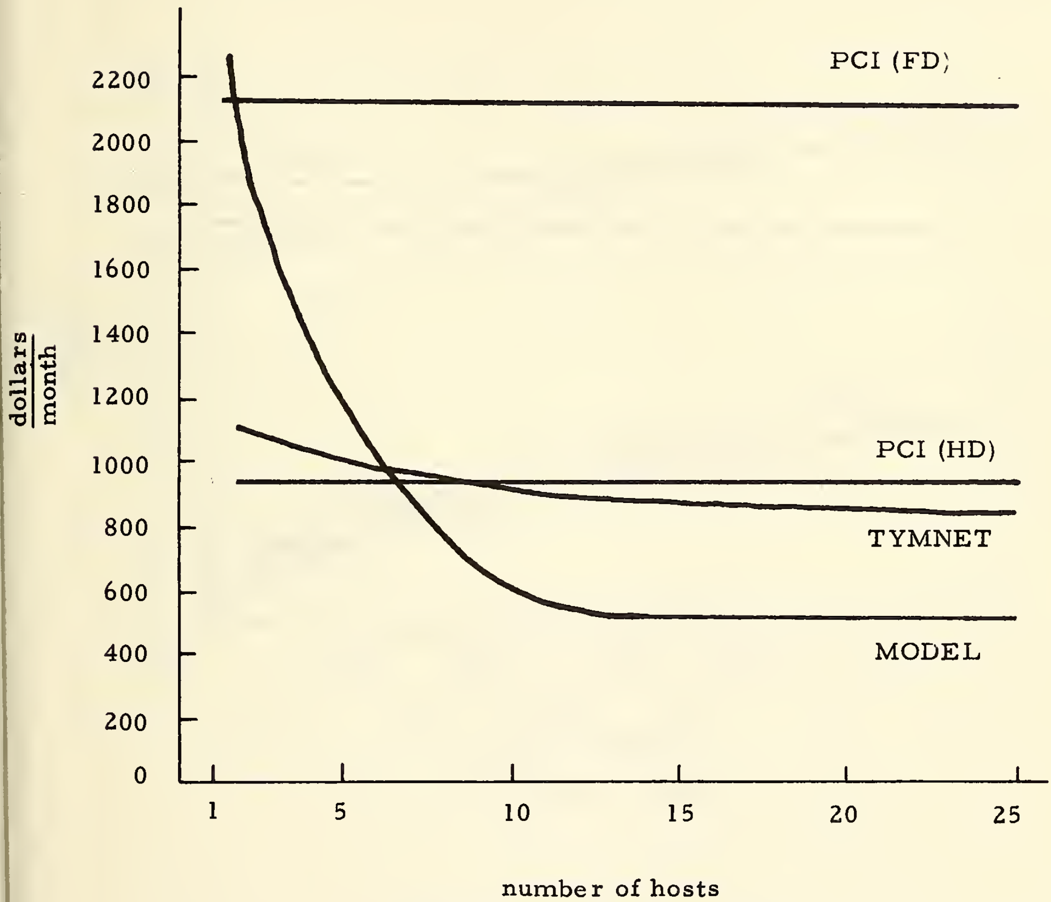
The following summarizes the communications costs derived by applying the cost factors of the two VAN's against the sample configurations. In addition the costs of the communication networks generated by the model are shown. The model, however, is limited to a maximum of twenty (20) servers. The numbers in parentheses are the costs of operating in full-duplex mode with echoing. As stated in section 5, these calculations assume the use of currently implemented ARPANET protocols for handling echoplex traffic. This should not imply that PCI will operate on echoplex in this inefficient manner.

SUMMARY

	TYMNET	PCI Illustrative (full-duplex)	Model
1 server/10 terminals	1143.50	996.60 (2158.90)	2220.00
1 server/100 terminals	813.00	623.55 (1308.20)	341.00
10 servers/100 terminals	942.00	996.60 (2158.90)	605.00
10 servers/1000 terminals	721.35	623.55 (1308.20)	262.00
20 servers/200 terminals	not calculated	not calculated	557.00
20 servers/2000 terminals			179.00
25 servers/250 terminals	889.50	996.60 (2158.90)	not derivable from model
25 servers/2500 terminals	715.24	623.55 (1308.20)	
minimum cost	711.17	526.70 (1210.70)	

MONTHLY COMMUNICATION COST PER TERMINAL

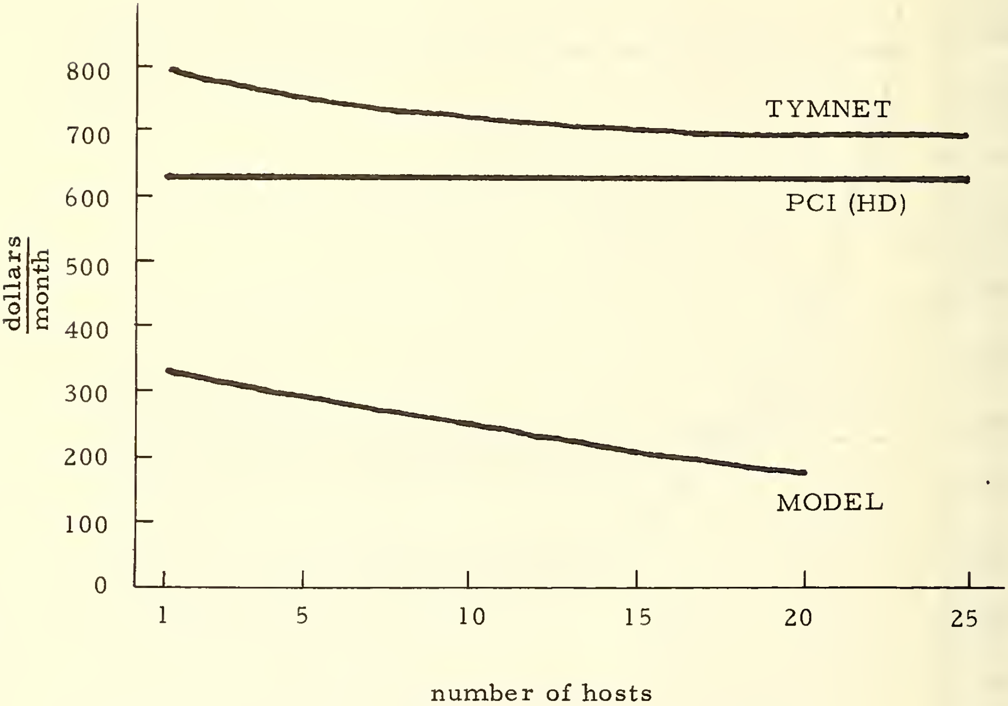
Figure 1 below shows the monthly communications cost per terminal with increasing size networks and a fixed host to terminal ratio of 1 to 10.



COST PER TERMINAL (1:10)

Figure 1

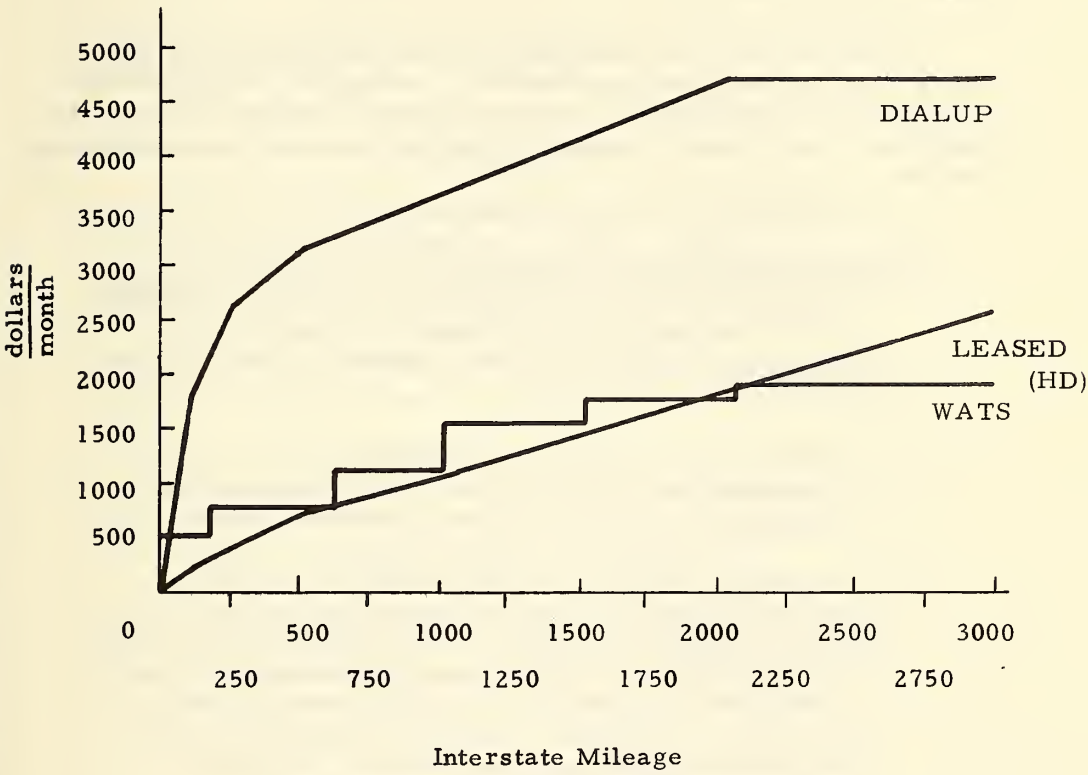
An economy of scale is evident in two of the networks. This is also apparent when the host to terminal ratio is increased to 1 to 100 as in Figure 2 below. It is also clear that the overall costs are substantially lower indicating that in the case of each network, there exists an economy of scale as the terminal to host ratio increases.



COST PER TERMINAL (1:100)

Figure 2

To put this information in perspective, Figure 3 below shows some costs for using common carrier provided facilities for one host and one terminal using the calculated traffic, connects, and holding times. Without multiplexing, costs for additional terminals are additive. The WATS portion of the graph is approximate since rates vary with location and WATS areas are non-symetric.



COMMON CARRIER FACILITIES

Figure 3

7. COMMENTS

This report has been intended to derive a set of approximations to the costs of networking using selected potential configurations and a particular type of common network traffic. The costs derived are to be reflective of the networking communications costs and do not include host computers, terminals, or local loops, but do include the interfaces between them and the network. It has been assumed, that in each configuration, every terminal has equal access to every host computer on the network.

It has not been the intent of this report to compare the cost of using alternative value-added networks. Although all of the networks are flexible in design and can accommodate geographically distributed connections, the networks cannot be directly compared for the following reasons:

1) TYMNET exists and is being used commercially.

2) ARPANET exists but the actual costs of using it are unknown. It is partially subsidized by ARPA, wide-band circuits are leased at a substantial volume discount, and costs associated with host interfacing have not been derived.

3) PCI has not yet created the proposed network, and if and when it is operational, it is not certain that the rates would be the same as the illustrative rates.

4) The network generated by the model, or the "do-it-yourself" approach, does not include operational overhead, marketing costs, installation charges, and a profit margin as do the commercial networks. It is strictly the equipment and circuitry costs that are generated. In addition some of the components would have to have special purpose software, and these developmental costs have not been included.

In addition to these pragmatic considerations, there exists a wide variety of support capabilities and performance differences. For a complete discussion see the technology review [3].

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APPENDIX A

Cost Calculations

In the following the cost per server node and the cost per terminal for each communication network is shown. Costs express one time installation charges and continuous monthly charges. Fixed scale costs, those for which the rate per unit is constant, and sliding scale costs, those for which the rate decreases with quantity, are identified separately. Traffic costs are the costs of transmitted data for one month for the number of specified terminals. Connects are the number of connections to the network made by the number of specified terminals in one month. The connect time is for the combined total of the specified number of terminals for one month.

The calculations are done differently for each communication network because the cost factors are different. The cost factors are identified in section 4. At the end of each set of calculations for a communication network, the minimum cost per terminal is shown. This is the cost when the network is large enough to approach costs based on the minimum rate of the sliding scale.

(1) TYMNET

Cost per server node - fixed scale:

installation = $5000 (approximate)

monthly = $2150 (30 ports maximum)

Cost per terminal - fixed scale:

traffic = $287.50
connects = $176.00
total = $463.50

Cost per terminal - sliding scale:

connect time =	0 - 500 hour	= $1500	
	500 - 2000	= $3750	$5250
	2000 - 5000	= $6000	$11,250
	5000 - 10,000	= $7500	$18,750
	10,000 +	= $1/hour	

Single server system:

A. 10 Terminals

installation	$5000
monthly	
server	$2150
fixed terminal	$4635
connect time	$4650
	$11,435
monthly cost/terminal =	$1,143.50

B. 100 Terminals

installation	
engineering	$1000
	x4 (120 ports)
	$4000
programming	$4000
	$8000
monthly	
server	$8600
fixed terminal	$46,350
connect time	$26,350
	$81,300
monthly cost/terminal =	$813.00

Ten Server System:

A. 100 Terminals

installation	$50,000
monthly	
server	$21,500
fixed terminal	$46,350
connect time	$26,350
	$94,200
monthly cost/terminal =	$ 942.00

B. 1000 Terminals

installation		
engineering	$ 1,000	
	x34	(1020 ports)
	$34,000	
programming	$40,000	
	$74,000	
monthly		
server	$73,100	
terminal	$463,500	
connect time	$184,750	
	$721,350	
monthly cost/terminal =	$721.35	

Twenty-five Server System:

A. 250 Terminals

installation	$125,000
monthly	
server	$53,750
fixed terminal	$115,875
connect time	$52,750
	$222,375
monthly cost/terminal =	$889.50

B. 2500 Terminals

installation		
engineering	$1,000	
	x84	(2520 ports)
	$84,000	
programming	$100,000	
	$184,000	
monthly		
server	$180,600	
terminal	$1,158,750	
connect time	$448,750	
	$1,788,100	
monthly cost/terminal =	$715.24	

Minimum cost/terminal:

server	$71.67
fixed terminal	$463.50
connect time	$176.00
	$711.17

(2) PCI Illustrative Rates

Cost per server node - fixed scale:

installation =	$8,000
monthly =	$3,250

Cost per terminal - fixed scale:

connect time =	$316.80

Cost per terminal - Sliding scale:

0 - 1500K packets	= $6000	
1500K - 3000K packets	= $5250	$ 11,250
3000K - 6000K packets	= $9000	$ 20,250
6000K - 9000K packets	= $7500	$ 27,750
9000K + packets	= $2/1000	

Single server system:

A. 10 Terminals

installation	$8,000	
monthly		
server	$3,250	
fixed terminal	$3,168	
traffic	$3,548	($15,171)
	$9,966	($21,589)
monthly cost/terminal	$996.60	($2,158.90)

B. 100 Terminals

installation	$8,000	
monthly		
server	$3,250	
fixed terminal	$31,680	
traffic	$27,425	($95,890)
	$62,355	($130,820)
monthly cost/terminal =	$623.55	($1,308.20)

NOTE: The number in parentheses is the cost of operating in full duplex mode with echoing. See comments on page 10.

Ten Server System:

A. 100 Terminals

installation	$80,000	
monthly		
server	$32,500	
fixed terminal	$31,680	
traffic	$35,480	($151,710)
	$99,660	($215,890)
monthly cost/terminal =	$996.60	($2,158.90)

B. 1000 Terminals

installation	$80,000	
monthly		
server	$32,500	
fixed terminal	$316,800	
traffic	$274,250	($958,900)
	$623,550	($1,308,200)
monthly cost/terminal =	$623.55	($1,308.20)

Twenty-five Server System:

A. 250 Terminals

installation	$200,000	
monthly		
server	$81,250	
fixed terminal	$79,200	
traffic	$88,700	($379,275)
	$249,150	($539,725)
monthly cost/terminal =	$996.60	($2,158.90)

B. 2500 Terminals

installation	$200,000	
monthly		
server	$81,250	
fixed terminal	$792,000	
traffic	$685,625	($2,397,250)
	$1,558,875	($3,270,500)
monthly cost/terminal =	$623.55	($1,308.20)

Minimum cost/terminal:

server	$32.50	
fixed terminal	$316.80	
traffic	$177.40	($861.40)
	$526.70	($1,210.70)

(3) Teleprocessing Systems Model

The costs for the concentrators and multiplexers are projected for 1974 from present costs and may in some cases be 10-15% less than the actual 1973 costs. Costs do not reflect host computer, local loop, or any special concentrator software. Below are examples of some typical equipment used and the related costs.

Multiplexers: monthly cost = $70 (8 ports)
Concentrators: monthly cost = $1080 (64 ports)
Switches (special concentrators): monthly cost = $1600
Circuits: interstate rates for voice grade and wideband

Concentrators can have two output ports giving them a limited message switching capability. Switches are concentrators that connect to all servers and have global knowledge of the network.

Single server system:

A. 10 Terminals

monthly

equipment	$ 2,700
circuits	$19,500
	$22,200
monthly cost/terminal =	$2,220.00

B. 100 Terminals

monthly

equipment	$ 6,630
circuits	$27,500
	$34,130
monthly cost/terminal =	$341.30

Ten Server System:

A. 100 Terminals

monthly

equipment	$11,500
circuits	$49,000
	$60,500

monthly cost/terminal = $605.00

B. 1000 Terminals

monthly

equipment	$49,600
circuits	$212,000
	$261,600

monthly cost/terminal = $ 261.60

Twenty Server System (model is limited to 20 servers maximum):

A. 200 Terminals

monthly	
equipment	\$21,600
circuits	\$89,800
	\$111,400
monthly cost/terminal =	\$557.00

B. 2000 Terminals

monthly	
equipment	\$94,700
circuits	\$263,000
	\$357,700
monthly cost/terminal =	\$178.85

APPENDIX B

Common Carrier Tariffs

Some typical common carrier tariffs are shown below. These are included to provide a comparison between common carrier rates and VAN rates used for this analysis.

Monthly charge interstate leased lines - voice grade:

MILES	HALF-DUPLEX (2-wire)	FULL-DUPLEX (4-wire)
25	$75.00	$82.50
+ 75 =100	+ 157.50=232.50	+ 173.25=255.75
+ 150 =250	+ 225.00=457.50	+ 247.50=503.25
+ 250 =500	+ 262.50=720.00	+ 288.75=792.00
+ 500 =1000	+ 375.00=1095.00	+ 412.50=1204.50
+ 1000 =2000	+ 750.00=1845.00	+ 825.00=2029.50
+ 1500 =3500	+ 1125.00=2970.00	+1237.50=3267.00

Interstate rates per month for dial-up service (assume 352, 1/2 hour calls) 8:00 a.m. - 5:00 p.m., Monday-Friday:

MILES	COST
100	$1826.88
250	2675.20
500	3203.20
1000	3731.20
2000	4752.00
3000	4752.00

Wide Area Telephone Service (WATS) rates per month for all six areas, full-time, based on Maryland location:

A1	A2	A3	A4	A5	A6
$510	$765	$1175	$1530	$1735	$1940
(180)	(500)	(1030)	(1500)	(2060)	(3000)

NOTE: Number in parenthesis is the approximate maximum mileage.

In the immediately preceding, the A1, A2, . . . , A6, refer to area zones in which calls are permitted. Every city in the country has 6 WATS areas associated with it; the smallest being A1 and the largest, A6, giving national coverage. Specific coverage and mileages are city dependent.

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

This report summarizes a communication cost study relevant to the needs of the NSF Networking for Science Program. The primary purpose of this report is to provide an approximation to the communications costs of connecting a specified number of host computers in selected locations with a specified number of interactive user terminals. Cost factors from existing, proposed, and modeled value-added networks are applied to hypothetical traffic demands to arrive at cost estimates.

17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons) Computer networking; cost study; interactive terminals; value-added networks.

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